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ABSTRACT

Ten years of Dobson spectrophotometer total ozone measurements and surface temperature observations at Wallops Island, Virginia, have been used to construct monthly mean values of the two parameters for the period 1972-1981. Both monthly mean data sets are most variable during January and February. The fluctuations in January in the monthly mean ozone amount and the mean surface temperature are correlated to a significant degree. The importance of stratospheric warmings in this correlation is discussed.

INTRODUCTION

There is considerable evidence that the atmospheric total ozone amount is strongly influenced by the general circulation. Beginning with the early work of Meetham (1937) and Fritz and Stevens (1950), studies have consistently shown that good correlation exists between the total ozone amount and stratospheric geopotential heights, stratospheric temperatures, and the tropopause height. Johansen (1958), Valovcin (1958), and Ohring and Muench (1960) expanded the scope of these investigations to include analyses of the correlation coefficient variations with season. The latter reference also included studies of the correlation coefficient variations with latitude by examining data records from more than one station.

A related body of work addressing the association of total ozone fluctuations with ridge and trough features included papers by Normand (1953) and Gowen et al. (1956). Many papers (Martin and Brewer, 1959; Newell, 1961; Newell, 1964; Hering, 1966; Newell et al., 1973; Wilcox, 1980; and others) have identified features of the atmospheric circulation that may be responsible for the ozone fluctuations. And, modelling studies

have more recently continued this area of investigation (Cunnold <u>et al</u>., 1975; Harwood and Pyle, 1977).

Recently, as the chlorofluorocarbon effects on total ozone have captured the attention of the scientific community, several studies have attempted to study the correlation of total ozone with these meteorological parameters over extended data records. Kulkarni (1976) examined total ozone records from four Australian ozone stations and found a significant trend at only one for the period 1963-1974. By examining the stratospheric temperature records at the 100 mb level over the same period, it was concluded that the ozone trend could be completely explained as the result of circulation changes. Newell and Wu (1978) computed the correlation coefficients for station-to-station differences in monthly mean total ozone amounts and concluded that the interstation relationships can be explained by a Hadley cell general circulation model. Furthermore, an examination of the long-term correlation between monthly mean total ozone and the stratospheric temperature in the 50-30 mb layer was shown to be consistent with a long-term decrease in the intensity of the Hadley cell circulation during the data period.

The purpose of this paper is to report a correlation between the total ozone measurements and surface temperature observations at Wallops Island, Virginia for the period 1972-1981. Complementary to the papers by Kulkarni (1976) and Newell and Wu (1978), the emphasis in this paper is placed not on the long-term trend in total ozone but on the year-to-year fluctuations that we must understand before the anthropogenic total ozone trends of ultimate interest can be identified.

Sources of Data

The data sets used in this study were both compiled at Wallops Island, Virginia. Surface weather observations have been made since 1960. Total ozone measurements have been made since 1967 using the Dobson spectrophotometer (Dobson, 1931). A double prism spectrometer, it is the recognized standard surface measurement device in ozonometry. Beginning in 1972, routine observations of total ozone have been made at 1500, 1700, and 1900 GMT when weather permits. The observations are made if possible using the AD line pair configuration recommended by the International Ozone Commission (IOC, 1968). Some observations of the zenith during overcast conditions are in the data base and are included in this study. A comment about the effect of these less accurate measurements on the monthly mean ozone amounts used in the analyses will be made later in the paper.

The monthly values of average total ozone and surface temperature were obtained in the following manner. The temperatures were retrieved directly from Weather Service Form F6 entitled Preliminary Local Climatological Data. The ozone amounts were computed

by averaging all 1500, 1700, and 1900 GMT Dobson measurements for each month. Because no observations can be made during precipitation, there is a built-in "fair weather" bias into the monthly mean ozone amounts. The behavior of the total ozone amount during weather features such as frontal passages is not known so the magnitude of this bias is undetermined.

DATA COMPARISONS

Table I contains the average monthly surface temperature data. Table II contains the climatological mean and standard deviation of the Table I averages for each month and the corresponding Weather Bureau climatological temperature means. The latter values were computed using data collected over the period 1941-70. Significant differences between the 1972-81 climatological monthly means and the 1941-70 climatological monthly means occur for March and December.

The average monthly total ozone values are in Table III, and the monthly ozone standard deviations are in Table IV. The units of both are m atm-cm or Dobson units (DU). For each month of 1980, the average monthly total ozone values were also computed using only Dobson observations directly of the sun. The zenith cloud observations were neglected. Then each month was compared with the values in Table III. The average difference for 1980 was -.167 Dobson units with a standard deviation of the differences

TABLE I. AVERAGE MONTHLY SURFACE TEMPERATURES FOR WALLOPS ISLAND, VIRGINIA IN °F

	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
J		37.3	43.0	40.4	34.8	25.7	33.6	36.0	37.9	30.4
F		36.5	37.9	40.6	44.2	35.6	30.4	28.9	32.1	38.5
M		48.1	46.7	44.0	47.9	47.4	42.6	44.7	41.7	42.5
A		53.3	54.6	49.6	55.4	56.5	54.5	53.3	54.7	55.4
M		61.5	62.5	63.4	60.6	63.3	59.2	63.1	64.8	61.0
J	67.2	72.5	69.2	73.2	70.7	69.9	69.8	68.6	70.8	73.5
J	75.0	78.0	75.6	74.9	74.0	78.2	73.8	76.8	75.0	77.3
A	75.5	76.1	74.7	78.6	73.5	77.4	78.0	77.5	75.8	73.5
S	70.9	72.8	68.0	70.1	69.3	72.2	70.1	72.3	72.1	68.7
O	57.0	61.0	55.0	62.6	55.5	57.0	57.7	59.5	57.1	57.2
N	48.5	49.8	48.5	54.2	42.1	50.2	52.3	53.0	47.3	48.4
D	45.8	43.0	41.7	42.1	37.9	38.4	41.5	43.1	38.5	38.2

TABLE II. CLIMATOLOGICAL SURFACE TEMPERATURES IN °F

	Mean ± 1σ	Weather Bureau (1941-70)
J	35.45 ± 5.19	36.2
F	36.08 ± 4.94	37.3
M	45.07 ± 2.51	39.9
A	54.14 ± 1.98	54.1
M	62.15 ± 1.72	63.3
J	70.54 ± 2.04	71.4
J	75.86 ± 1.60	76.2
A	76.06 ± 1.81	75.2
S	70.65 ± 1.67	69.9
O	57.96 ± 2.38	60.2
N	49.43 ± 3.42	49.4
D	41.02 ± 2.66	38.8

TABLE III. AVERAGE MONTHLY TOTAL OZONE AMOUNTS AT WALLOPS ISLAND, VIRGINIA IN DU

	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
J		321	311	299	326	402	338	352	317	340
F		366	363	323	310	391	344	357	369	349
M		352	372	355	335	355	344	369	355	375
A		377	372	372	345	374	339	382	373	350
M		373	358	354	351	391	351	350	360	364
J	368	336	352	344	338	367	339	342	356	325
J	342	332	341	327	332	340	330	333	328	328
A	322	327	318	317	325	320	312	321	322	326
S	318	307	296	301	316	309	305	293	303	307
O	309	304	306	285	312	307	297	300	306	296
N	310	297	279	287	316	290	278	283	287	301
D	302	302	306	301	316	316	294	309	321	323

of 3.95 D.U. That is, on the order of 5 DU change in any month's values in Table III can be attributed to the effects of the less accurate zenith cloud Dobson observations. The climatological mean ozone amounts computed from Table III and the climatological average standard deviations from Table IV are listed in Table V.

TABLE IV. MONTHLY OZONE AMOUNT STANDARD DEVIATIONS IN DU

	1972	1973	1974	1975	1976	1977	1978	1979	1980	1982
J		36	27	36	38	46	36	35	28	34
F		39	29	32	28	51	44	32	38	32
M		33	48	39	29	34	33	26	35	40
A		55	33	37	30	41	21	35	33	33
M		35	34	25	27	40	32	24	22	37
J	30	24	22	26	19	25	17	17	31	18
J	21	16	17	23	11	19	17	21	12	9
A	16	21	20	17	11	11	10	19	10	24
S	17	14	14	19	10	12	9	17	20	14
O	26	21	28	14	21	20	21	25	14	21
N	26	46	22	19	22	23	19	18	22	23
D	39	31	26	23	23	32	32	28	21	37

TABLE V. CLIMATOLOGICAL OZONE MEANS AND STANDARD DEVIATIONS

	Average Monthly Mean ± 1σ	Average Monthly Standard Deviation ± 1σ
J	334 ± 30.16	35.1 ± 5.55
F	352.4 ± 24.57	36.1 ± 7.61
M	356.9 ± 13.15	35.78 ± 6.48
A	364.9 ± 15.72	35.39 ± 9.15
M	361.3 ± 13.38	30.67 ± 6.36
J	346.7 ± 13.86	22.9 ± 5.17
J	333.3 ± 5.68	16.6 ± 4.67
A	321.0 ± 4.55	15.9 ± 5.13
S	305.5 ± 7.86	14.6 ± 3.66
O	302.2 ± 7.91	21.1 ± 4.58
N	292.8 ± 12.91	24.0 ± 8.08
D	309.0 ± 9.63	29.2 ± 6.07

From Table V and Table II, it can be seen that in January and February the year-to-year fluctuations in total ozone and in surface temperature are the maximum for the year. This suggests that the correlation between the two quantities may be strongest for those two months. The correlation coefficients between the monthly mean ozone amount and surface temperature have been computed for each month and the results are shown in Table VI.

TABLE VI. CORRELATION COEFFICIENTS DESCRIBING MONTHLY MEAN TOTAL OZONE AND SURFACE TEMPERATURE RELATIONSHIPS

Month	No. of Pairs	r
J	9	-.8767
F	9	-.5457
M	9	-.2545
A	9	-.3236
M	9	.2457
J	10	-.6592
J	10	.1868
A	10	-.6556
S	10	-.0139
O	10	-.7149
N	10	-.6914
D	10	-.7588

DISCUSSION

The January correlation coefficient is significant at better than the 1% level. The value for this particular month is high mainly because of January 1977, when the temperature at the surface was a minimum at 25.7°F and the total ozone was a maximum at 402 Dobson units. The next highest correlation was for December but the range of total ozone for that month and the range of temperatures are much smaller than for January. In February, there was an elevated ozone value of 391 DU in 1977 indicating the persistence of the January event mentioned above. However, the overall correlation for February is reduced from January's. With February's large interannual range of temperature and total ozone, it was expected that the good correlation found in January would also be found in February. A good correlation does exist if 1978 and 1979 are omitted from the regression. A possible explanation for this difference will be presented below. The r values for the other months will not be considered because the small range of variation of mean temperature and ozone limits the meaningfulness of the correlations.

For January, the event of 1977 can be explained with some certainty for that was the month when a severe sudden stratospheric warming (SSW) occurred (McGuirk, 1978). Since 1952 when the SSW phenomenon was discovered (Scherhag, 1952), only four have

approached the severity of the 1977 event. The others occurred in January and February of 1958, January 1963 and January 1971 (McGuirk, 1978). The warmings occur much more frequently but for a still unexplained reason, some have more impact on the troposphere and our weather than do others. As reported by Quiroz (1977), the 1977 SSW extended from 10 mb down to the surface. Following the onset of the SSW in the stratosphere, blocking of the synoptic-scale wave patterns occurred leading to the advection of ozone-rich, intensely cold arctic air into the eastern half of the United States. As reported by Dickson (1978), the winter month of February 1978 was anomalously cold. In fact, the tropospheric circulation pattern was very similar to that of January 1977. However, Hudson and Reed (1979) point out that in the February 1978 case a circulation reversal in the stratosphere did not occur because of a strong tropospheric poleward pressure gradient during the major SSW in February. Without the circulation reversal, less ozone was apparently advected towards mid-latitudes. The colder temperature of February 1978 and lower ozone amount than expected for that temperature thus explain the poorer correlation for February. For years other than 1977 and 1978, it is not known if the surface temperatures are influenced by the minor warmings in the stratosphere and any accompanying changes in the general circulation. But, the high degree of interannual variability in both the temperature and total ozone data sets for January and February coincides with the period when SSW's are observed. Further study is needed to determine if SSW's are involved in year-to-year differences in tropospheric synoptic-scale flow patterns.

CONCLUSIONS

Based upon ten years of surface temperature and Dobson total ozone measurements at Wallops Island, Virginia, it has been found that:

1. The interannual variability between averaged monthly values of temperature and total ozone is large, especially for the months of January and February.
2. This variability in the winter months can be explained as the result of the advection of arctic air resulting from sudden stratospheric warmings.
3. The correlation between high ozone values and abnormally low surface temperatures is significant for the month of January.

With the great attention being given to ozone trends over time spans of decades, there must be attention given to the natural fluctuations which ozone experiences before the anthropogenic effects can be understood. This note points to SSW as a mechanism that does influence the ozone levels. It must therefore be considered in ozone trend analyses.

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